Review of Environmental Research Specific to Smart Weapons Operability Enhancement for the Battlefield Environment

James P. Welsh
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, NH

Mike Hardaway
U.S. Army Topographic Engineering Center
Fort Belvoir, VA

Wade West
U.S. Army Waterways Experimentation Station
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FOREWORD

SWOE Report 92-2, 22-25 June 1992, was prepared by Dr. J. P. Welsh of U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, M.Hardaway of U.S. Army Topographic Engineering Center, Fort Belvoir, Virginia and H.W. West of U.S. Army Waterways Experiment Station, Vicksburg, Mississippi.

This report is a contribution to the Smart Weapons Operability Enhancement (SWOE) Program. SWOE is a coordinated, Army, Navy, Marine Corps, Air Force and DARPA program initiated to enhance performance of future smart weapon systems through an integrated process of applying knowledge of the broadest possible range of battlefield conditions.

Performance of smart weapons can vary widely, depending on the environment in which the systems operate. Temporal and spatial dynamics significantly impact weapon performance. Testing of developmental weapon systems has been limited to a few selected combinations of targets and environment conditions, primarily because of the high costs of full-scale field tests and limited access to the areas or events for which performance data are required.

Performance predictions are needed for a broad range of background environmental conditions and targets. Meeting this need takes advantage of significant DoD investments by Army, Navy, Marine Corps and Air Force in 1) basic and applied environmental research, data collection, analysis, modeling and rendering capabilities, 2) extensive target measurement capabilities and geometry models, and 3) currently available computational capabilities. The SWOE program takes advantage of these DoD investments to produce an integrated process.

SWOE is developing, validating, and demonstrating the capability of this integrated process to handle complex target and background environment interactions for a world-wide range of battlefield conditions. SWOE is providing the DoD smart weapons and autonomous target recognition (ATR) communities with a validated capability to integrate measurement, information base, modeling and scene rendering techniques for complex environments. The result of a DoD-wide partnership, this effort works in concert with both advanced weapon system developers and major weapon system test and evaluation programs.

The SWOE program started in FY89 under Balanced Technology Initiative (BTI) sponsorship. Present sponsorship is by the U.S. Army Corps of Engineers (lead service), the individual services, and the Joint Test and Evaluation (JT&E) program of the Office of the Director of Defense Research and Engineering (DDR&E), Office of the Secretary of Defense (OSD).

The Program Director is Dr. L.E. Link, Technical Director of the U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL). The Program Manager is Dr. J.P. Welsh, CRREL. The Integration Manager is Mr. Richard Palmer, CRREL. The task areas and their managers are as follows: Modeling Task Area, LTC George G. Koenig, USAF, Geophysics Laboratory (GL), of the Air Force Phillips Laboratories; Information Bases Task Area, Mr. Harold W. West, PE, U.S. Army Engineer, Waterways Experiment Station (WES); Scene Rendering Task Area, Mr. Mike Hardaway, Corps of Engineers, Topographic Engineering Center (TEC); Validation Task Area, Dr. Jon Martin, Atmospheric Sciences Laboratory (ASL) of the Army Materiel Command.

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*Dr. James P. Welsh, U.S. Army Corps of Engineers, Cold Regions Research & Engineering Laboratory, Smart Weapons Operability Enhancement, 72 Lyme Road, Hanover, NH 03755-1290

Mr. Mike Hardaway, U.S. Army Corps of Engineers , Topographic Engineering Center, Fort Belvoir, VA 22060-5546

Mr. Wade West, U.S. Army Corps of Engineers, Waterways Experimentation Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

ABSTRACT: The Smart Weapons Operability Enhancement (SWOE) Program is developing, validating, and demonstrating an integrated, physics based, scene generation process to consider complex target and background environment interactions for a world wide range of battlefield conditions. The primary product of this program is an integrated process that will enhance the performance of future smart weapons systems for a global variety of battlefield environments. The validated capability combines methodologies and techniques that comprehensively treat environment interactions relevant to smart weapon performance. This capability is being developed and demonstrated for Department of Defense (DoD) wide user communities. The "weapon system environment" is number 11 on the DoD critical technologies list. "Synthetic Environments" is one of the principal thrust areas for DoD Science and Technology. Components of the environment have been quantitatively shown to impact the performance of electromagnetic and electro-optical weapon systems. The SWOE program incorporates capabilities from the Army, Navy, Marine Corps and Air Force technology base programs. This paper summarizes some of the coordinated efforts, by Corps of Engineers (CoE), laboratories in the technology base program. The laboratories are: Cold Regions Research and Engineering Laboratory, Waterways Experiment Station and Topographic Engineering Center. The SWOE program has provided a focus for coordinated and cooperative investigations of critical environment factors and processes that significantly impact weapon performance. These studies have considered the broadest possible range of anticipated battlefield environmental conditions. The principal thrust has been to quantitatively define these factors and to provide the capabilities to measure, model, render and extrapolate the environmental impact on weapon performance.

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SWOE Scene Generation Process

The SWOE scene generation process is an integration of measurement, information bases, models and rendering capabilities. The CoE tech Base effort, relevant to SWOE, is focused in four areas: measurements, information bases, modeling, and rendering.

Measurement and Information Bases

What, where, when, and how to measure, to obtain representative samples, and infer energy interactions between surface and volume scatters (including spatial scales of less than 0.5 meters). Construction of information bases for a global variety of battlefield environment conditions, particularly to develop site-to-site and area-to-area comparisons methods.

Figure 1 summarizes the CoE effort for measurement and information bases.

Figure 1. Tech Base Measurement & Information Bases

Δ WES □ TEC ○ CRREL

TASK			
Measurements	Classification & Regression Based Winter Parameters ○ Standardize Snow Microstructure Methods ○ 3-D Scene Parameters Temperate ○Δ 35 GHz Measurements Temperate ○Δ	95 GHz Measurements Temperate & Desert ○Δ Forest Edge MMW Temperate ○Δ Slant Range IR Temperate & Desert ○Δ Forest Edge IR Temperate ○Δ	Winter Scene Sampling ○ Surface Energy Exchange in Winter ○ Surface Scatter Polarimetrics ○Δ
Evaluation	IR Metrics Ground to Ground ○Δ	MMW Metrics Air to Ground ○Δ IR Metrics Air to Ground ○Δ Correlation to Scenes ○Δ	MMW Metrics Ground to Ground ○Δ
Info Bases	Data Compression Δ Interface GIS & DBMS Δ Texture Reference Data Δ	Microstructure Info Base Snow Covered Area ○ Prototype 3-D Temperate, Desert & Tropic Info Bases ○Δ Transient Atmospheric Phenomena Info Base ○ Enhanced Data Base Procedures Δ	MMW Signature Data Base ○Δ IR Signature Data Base ○Δ Enhanced Data Compression Δ

An integral part of the 3-D scene generation procedure, the information base contains all spatial and attribute data required to define the total landscape environment (land, water, atmosphere, sky, etc.). The content and structure of the information base are driven largely by the various requirements of the numerical models and the scene generation software.

The information base contains three kinds of data: digital terrain data (e.g., topography, soil types, vegetation types); physical, thermal, and spectral terrain attribute data (e.g., moisture content, emissivity, reflectance); and meteorological (weather and atmospheric) data (e.g., air temperature, visibility).

Digital terrain data are representations of portions of the earth's surface stored in computer-compatible formats. These data depict characteristics such as elevation, vegetation types, soil types, and other relevant environmental information. Digital terrain data used in the scene generation procedure are stored in raster and vector formats and managed by a geographic information system (GIS).

The physics-based thermal signature prediction models used in the scene generation procedure require as inputs complete, quantitative descriptions of the physical, thermal, and spectral attributes of each landscape feature. These data are most efficiently stored and retrieved in tubular format in a relational database management system (RDBMS). The RDBMS associates each stored numerical value with the corresponding landscape feature depicted in the GIS.

Meteorological data are required throughout the scene generation process and have particular importance to the radiation field prediction models. Both surface weather and upper atmospheric profile data are required. These data are also stored in tabular format in the RDBMS.

Models

The goal of the SWOE modeling effort is to assemble and integrate 3-D fundamental physics models of important environment phenomena and objects (natural & manmade) for the IR and MMW spectral bands. Specific objects are: trees, with & without leaves, buildings, vehicles, roads, bridges, etc. The boundary regions between adjacent objects, tree canopies, row crops, forest edges, and other textured surfaces are also important. Models of the energy budget are significantly effected by heterogeneity in the 3-D distribution of energy emitters and scatters.

Figure 2 summarizes the CoE effort relevant to modeling.

Figure 2. Tech Base Modeling

Δ WES □ TEC ○ CRREL

Task				
Energy Budget	3-D Models	Geometric Mesh & Mechanics For 3-D Multiphase Calculations ○ Radiosity & Ray Tracing Methods For 3-D Δ Low Resolution Mesoscale Weather Model Δ	3-D Multiphase Snow & Soil Model ○ Intermediate Resolution Mesoscale Weather Model Δ	3-D Model With Water Transport ○ Total Energy Flux Model Δ High Resolution Mesoscale Weather Model Δ
Energy Budget	IR	First Generation Laser Scattering Model Δ	IR Scene Composit Models (Buildings, Cultural Features Etc.) ○ Δ	
Energy Budget	MMW	Evaluation Of Lang 35GHz Snow & Vegetation Models ○ Active & Passive Signature Modeling Concepts ○ Δ	Extension Of Lang Model To 95 GHz For Snow ○ First Gen Coupled 35 GHz Surface & Volume Scattering Models (Shi) ○ Interim Single Band Signature Model Δ	Extension Of Lang Model To 95 GHz For Vegetation ○ Integrate 35 GHz Lang & Coupled Models (Lang / Shi) ○ Multi-band Signature Model ○ Δ
Texture	IR	Statistical IR Snow Relations ○ Second Generation Synthetic IR Texture Procedure Δ	Statistical IR Mixed Snow & Ground Model ○ First Gen Physics Based Texture Models ○ Δ	Hybrid IR Snow & Frozen Ground ○ Refined Physics Based Texture Models Δ
Texture	MMW	First Generation Synthetic MMW Texture Concepts ○ Δ	Statistical MMW Snow Texture Model ○ First Generation MMW Vegetation & Soils Synthetic Texture Model Δ	Statistical MMW Mixed Snow & Ground Model ○ Enhanced MMW Vegetation & Soils Texture Model Δ
Boundary Layer			Model For Turbulent Heat Flux Exchange ○	Mesoscale Transient Boundary Layer Model ○

The SWOE Interim Thermal Model is used to calculate the surface temperatures for a wide variety of surfaces, including vegetated and non-vegetated surfaces, bodies of water, and snow/ice-covered surfaces. The model results are valid for all seasons.

The thermal models, in the package, are driven by conventional weather data, such as standard surface weather observations and radiosonde data. Default databases of seasonally dependent thermal properties are provided to cover a set of standard surfaces that are commonly encountered in scene simulation.

The SWOE thermal models package accommodates various vegetation effects. The effects of simple vegetation, such as grasses and crops, and forests can be included

in the 1-D heat balance of soils. A separate 3-D model of the thermal balance for individual trees is included. Two geometric representations of trees, based on measurements of actual trees, have been included to calculate the temperature fields for trees.

The SWOE thermal models are driven by the radiation fields from the atmosphere. The atmospheric radiation budget is calculated using a modified version of LOWTRAN7, which is the standard atmosphere radiance and transmission code used by the DoD community.

The SWOE Radiance models software system contains two parallel computational paths, one for terrain and one for 3-D objects (currently individual trees and two military targets). The terrain radiance path is built around a new Fortran model, called IBRM ("Improved Background Radiance Model"). Radiance's for 3-D objects are computed with the Hardbody module of the SPIRITS code, a U.S. Government standard for aircraft. Both radiance models utilize the same basic algorithms and phenomena, which include:

• radiance's computed spectrally at 2 to 20 cm-1 resolution, and bandpass integrated (with optional filter function) only after atmospheric effects are added;

• radiance sources of thermal emission, the sun, the sky, and surrounding terrain;

• sky emission from broken clouds;

• solar shadowing;

• spectral directional emissivities for each material;

• a spectral bidirectional reflectivity for each material;

• spectral atmospheric transmission and radiance (thermal and solar scatter) along all paths connecting the terrain, sun, sky, and sensor, utilizing the Air Force MODTRAN model (an upgrade to LOWTRAN7).

A separate model, SHADOW, automatically generates faceted shadows of the 3-D objects for inclusion within the scene.

The terrain is modeled with a set of textured polygons which overlay the topography grid. The polygon definitions and geometry are determined as part of the information base effort. The radiance models software computes a list of in-band radiance's for each polygon, based in part on temperatures computed by the SWOE thermal models.

Trees and targets are described with a triangular geometry, typically with 3000 to 20,000 triangles per object. Tree geometry's are based on trunk and branch measurements taken from sets of real tree measurements. Faceted leaves are generated using a fractal technique. The resulting geometry, plus a file with a separate temperatures for each triangle, are input to Hardbody for the tree radiance computations.

Targets require that the user have or prepare ahead a set of computed target temperatures for the scene specified conditions; Hardbody then computes the radiance's. Utility software is provided to convert thermal computations to the Hardbody format. Hardbody computations include facet-to-facet reflections, in addition to the those listed above. It also computes images for the objects as individuals.

Clouds are one of the more important modulators of the surface energy balance. The SWOE model package considers the influence of clouds for solar and infrared downwelling flux. During the thermal loading phase, also known as the model spin-up phase, a simple model is used to modulate the broadband downwelling flux in both spectral regions based on the geographical location of the scene, time, surface characteristics (slope and albedo), atmospheric conditions, cloud amount, and cloud type. This approach does not provide the radiant field information required at the time of the scene simulation. At scene simulation time a modified version of LOWTRAN is used to calculate the spectrally dependent solar direct and diffuse, and infrared downwelling flux. This information is used in the computation of reflections off of and between scene elements; and absorption and scattering by atmospheric gases, aerosols, and clouds. Cloud shadows at the time of the scene simulation are generated by the Cloud Scene Simulation Model (CSSM). The CSSM uses a Successive Random Additions (SRA) fractal algorithm to generate the horizontal distribution of the clouds based on the cloud amount and type (stratiform, cirriform, or cumuliform). 1-D SRA and 2-D SRA algorithms are used to generate the upper and lower surface of the cloud while a 3-D SRA algorithm is used to modulate the liquid water density (LWD) information at each cloud grid point in the cloud volume. The mean LWD information as a function of cloud type and altitude has been obtained from an extensive cloud database. In the future, the LWD information will be used to determine the cloud microphysical and optical properties for use in a model that will calculate the full 3-D cloud radiative interactions. The scene generated cloud characteristics are controlled by the Hurst and Lacunarity parameters in the SRA algorithm. Model default values controlled by the cloud type are used in the cloud simulation, but the user can modify these parameters. Cloud shadows are determined using a ray tracing technique, the 3-D cloud spatial distribution, and the solar azimuth

and zenith angle or scene location and time of year and day. More detailed information on the SWOE model package, can be obtained from SWOE technical reports, listed in Appendix 1.

Rendering

The rendering effort of the CoE laboratories is summarized in figure 3.

Figure 3. Tech Base Scene Rendering

△ WES □ TEC ○ CRREL

	TASK			
Object Rendering	2-D Features	Standard Data Structures □	Non- Standard Data Structures □	
Object Rendering	3-D Solids	Initial Model Library □ Solid Model Insertion □	Expanded Model Library □ Solids Model Interactions □ Textured Ellipsoid □	Model Library Editing Functions □ Dynamic Models □
Object Rendering	Amorphous Objects	COMBIC Smokes □ Multiple Point Sources □	Other Obscurrents □ Clouds / Fog / Haze / Humidity □	Terrain / Wind Dynamics □
Techniques	Texture	Synthetic IR Texture Mapping □	Pixel Map Texturing □	Physics Based Texture □
Techniques	Rendering	Terrain Shadowing □ Anti-Aliasing □ Filtering / Smoothing □	Attribute Capability □ Integrated Z-Buffering / Ray Tracing / Textured Ellipsoid □ Solids Objects Shadowing □	Amorphous Object Shadowing □ Tracker Algorithm □ Radiosity Rendering □
Techniques	MMW	Technology Assessment □ Preliminary Geometry □	Interface Sensor Models □	Initial Phase / Brightness Soft ware □

The SWOE rendering software provides the capability necessary to create 2-D visualization of 3-D objects and backgrounds. The software uses the depth buffer approach to resolve hidden surfaces. The output is a projection of the data contained in the information base onto a 2-D image or pixel file. The input files contain physics models, initialization information, haze and lighting, and viewpoint . These

inputs are used to generate the pixel data to create an image using the following processes:

- Viewpoint manager - processes input initialization data and viewpoint information to generate a sun vector, ambient and diffuse lighting parameters, bounding planes, and the world space to a viewpoint space transformation matrix, which is referred to as "viewpoint data".

- World manager - uses viewpoint data and bounding planes to select root nodes in the data base for the terrain region. A node is defined as a subset of the information base which contains position data, information for level of detail (LOD) and field of view (FOV), materials properties, etc. and pointers to the items associated with each node.

- Node processor - traverses the node tree and uses the bounding planes to determine which nodes are in the FOV. The FOV test creates a list of active nodes, loads texture maps and allocates nodes to the correct LOD.

- Item processor - transforms sun vectors, calculates triangle face normals, eliminates back faces, determines polygon coloring and shading, converts vertices to viewpoint space, clips to hither plane, and projects polygons to screen space.

- Pretiler - clips polygon to screen space and creates triangles with incremental color, depth, and texture information.

- Tiler - produces pixels for display for each triangle through the graphics processor, and may modify color attributes of textured items.

The result of the rendering is a 2-D pixel space representation of the radiometric energy arriving at the aperture of a sensor for a specified viewing geometry.

Summary and Conclusions

The SWOE concept, as developed, depends on the research products of DoD technology base programs. The CoE technology base contributions to the SWOE program are significant. CoE has taken the lead by commitment to a focused tech base effort required for enhancement of future smart weapon system performance. This commitment has resulted in extremely high levels of coordination and cooperation between CoE laboratories, as well as, serving as a model for unprecedented levels of coordination and cooperation between all the armed forces in the SWOE program.

Appendix 1

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13. ABSTRACT (*Maximum 200 words*)
The Smart Weapons Operability Enhancement (SWOE) Program is developing, validating, and demonstrating an integrated, physics based, scene generation process to consider complex target and background environment interactions for a world wide range of battlefield conditions. The primary product of this program is an integrated process that will enhance the performance of future smart weapons systems for a global variety of battlefield environments. The validated capability combines methodologies and techniques that comprehensively treat environment interactions relevant to smart weapon performance. This capability is being developed and demonstrated for Department of Defense (DoD) wide user communities. The weapon system thrust areas for DoD Science and Technology. Components of the environment have been quantitatively shown to impact the performance of electromagnetic and electro-optical weapon systems. The SWOE program incorporates capabilities from the Army, Navy, Marine Corps and Air Force technology base programs. This paper summarizes some of the coordinated efforts, by Corps of Engineers (CoE), laboratories in the technology base program. The laboratories are: Cold Regions Research and Engineering Laboratory, Waterways Experiment Station and Topographic Engineering Center. The SWOE program has provided a focus for coordinated and cooperative investigations of critical environment factors and processes that significantly impact weapon performance. These studies have considered the broadest possible range of anticipated battlefield environmental conditions. The principal thrust has been to quantitatively define these factors and to provide the capabilities to measure, model, render and extrapolate the environmental impact on weapon performance.

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